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Magnetic properties of $R_2Fe_{14}Ga_2$ ($R = Y, Nd$ and Sm)

Z W Li and A H Morrish

Department of Physics, University of Manitoba, Winnipeg, Canada R3T 2N2

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Abstract. Crystal structures and magnetic properties for off-stoichiometric $R_2Fe_{14}Ga_2$ ($R = Y, Nd$ and Sm) have been studied by using x-ray diffraction, magnetic measurements and Mössbauer spectra. All compounds have the Th_2Zn_{17} structure. The Curie temperatures increase by about 150–200 °C. over those for the corresponding R_2Fe_{17} compound. $Y_2Fe_{14}Ga_2$ and $Nd_2Fe_{14}Ga_2$ have an easy c plane anisotropy and $Sm_2Fe_{14}Ga_2$ has an easy c axis anisotropy. The increase of the Curie temperatures and the change of the anisotropy are discussed in terms of the site occupancy by the Ga atoms.

1. Introduction

R_2Fe_{17} compounds are not useful as permanent magnets because of their low Curie temperatures and planar anisotropies at room temperature. Many investigations have been made to modify their magnetic properties by partial substitution of different elements such as Si and Al for Fe [1–13]. All of these substitutions can elevate the Curie temperature, but cannot change the anisotropy from an easy c plane to an easy c axis. Recently, Pouraian *et al* [14] have discovered that, in contrast to $R_2Fe_{15}Si_2$ compounds, the off-stoichiometric compounds $R_2Fe_{14}Si_2$ ($R = Y, Nd, Gd, Dy$ and Ho) with the 2:17-type crystal structure have an easy c axis anisotropy. In addition, it has been reported that $Sm_2Fe_{14}Si_2$ has an easy c plane anisotropy as does $Sm_2Fe_{15}Si_2$ [15]. These results indicate that Si atoms play an important role in determining the easy magnetization direction of the Fe and R sublattices. On the one hand, the easy c axis anisotropy for Y and Gd compounds has its origin in the Fe sublattice. Pouraian *et al*, therefore, suggested that the Si site occupation has a strong effect on the local anisotropy of the Fe atoms on the 6c/4f sites so that the anisotropy for the Fe sublattice is turned from the easy c plane into the easy c axis. On the other hand, to understand the easy c plane anisotropy for the Sm compound and the easy c axis anisotropy for Nd, Dy and Ho compounds, Pouraian *et al* supposed that Si atoms must change the sign of α_1 (the second-order Stevens coefficient) from positive to negative.

The effect of Si atoms on the anisotropy has attracted much attention. The question is whether or not other elements can play the same role as Si in modifying the magnetic anisotropy. For many R–Fe compounds, Ga atoms play a role similar to that of the Si atoms. For example, both are able to elevate the Curie temperatures and reduce the saturation magnetizations for R_2Fe_{17} [13] and $R_2Fe_{14}B$ [16, 17]. In this work, the off-stoichiometric $R_2Fe_{14}Ga_2$ ($R = Y, Nd$ and Sm) compounds have been prepared and the effect of Ga atoms on the crystal structure and magnetic properties studied by x-ray diffraction, magnetic measurements and Mössbauer spectra. Some results, such as the Curie temperature, are similar to those for $R_2Fe_{14}Si_2$; however, some results, such as anisotropy, are greatly different from those for $R_2Fe_{14}Si_2$.

2. Experimental details

Samples of $R_2Fe_{14}Ga_2$ ($R = Y, Nd$ and Sm) were prepared by arc melting under an Ar atmosphere. The purities of the starting materials were 99.8% R, 99.9% Fe and 99.9% Ga. An excess of the rare earth constituent (2% for Y and Nd and 5% for Sm) in the composition is added to compensate for the rare earth loss in melting. The ingots were remelted at least three times in order to achieve homogeneity. Then, the ingots were annealed at 1200 K for 4 h.

X-ray diffraction experiments were performed using a diffractometer with Fe K α radiation. Curie temperatures were obtained from a thermomagnetic scan in an applied field of 0.5 kOe. The specific magnetizations, $\sigma(H)$, were measured using a vibrating sample magnetometer in applied fields up to 18 kOe at room temperature; the saturation magnetizations were found by fitting the experimental $\sigma(H)$ values plotted against $1/H$ using the law of approach to saturation. To measure the magnetic anisotropy fields, aligned samples were prepared by mixing the fine powders with epoxy resin and then placing the mixture in a magnetic applied field of 10 kOe. ^{57}Fe Mössbauer spectra were taken at room temperature using a conventional constant-acceleration spectrometer. The γ -ray source was ^{57}Co in an Rh matrix. Calibration was performed by using the spectrum of α -Fe at room temperature.

3. Results and discussion

3.1. X-ray diffraction

X-ray diffraction patterns are shown in figure 1. The $R_2Fe_{14}Ga_2$ ($R = Y, Nd$ and Sm) are single phases with the Th_2Zn_{17} structure except for the Sm compound, for which a small amount of α -Fe was detected. For the Y compound, substitution of Ga for Fe leads to a structural change, from the Th_2Ni_{17} structure as for Y_2Fe_{17} to the Th_2Zn_{17} structure.

Table 1. Crystal structure parameters for $R_2Fe_{14}Ga_2$.

a (Å)	c (Å)	V (Å ³)	$\Delta V/V$ (%)	
$Y_2Fe_{14}Ga_2$	8.576	12.498	796.1	3.00
Y_2Fe_{17} [18]	8.466	12.450	772.8	
$Nd_2Fe_{14}Ga_2$	8.647	12.586	815.0	2.63
Nd_2Fe_{17} [18]	8.578	12.462	794.1	
$Sm_2Fe_{14}Ga_2$	8.633	12.438	802.8	1.84
Sm_2Fe_{17} [18]	8.553	12.443	788.3	
$Sm_2Fe_{15}Ga_2$ [13]	8.674	12.515	810.6	

The lattice parameters for $R_2Fe_{14}Ga_2$ are listed in table 1. In addition, the lattice parameters for R_2Fe_{17} [18] and stoichiometric $R_2Fe_{15}Ga_2$ [13] are also listed in the table. The substitution of Ga for Fe leads to an increase in the lattice parameters and cell volumes. The increases are attributed to a larger size for a Ga atom as compared to an Fe atom.

There are two possible structures for the off-stoichiometric $R_2Fe_{14}Ga_2$ with the 2:17-type structure. (i) An R atom is substituted for some of the pairs of Fe atoms on the dumbbell site (6c site). The chemical formula of $R_2Fe_{14}Ga_2$ should then be written as $R_2(R_{0.006}Fe_{0.864}Ga_{0.124})_{17}$. This substitution will lead to an increase in the cell volume because the size of the R atoms is much larger than the size of either Fe or Ga atoms.

(ii) Some vacancies exist in the lattice. The vacancies will result in a decrease in the cell volume. Because of the smaller lattice parameters for the off-stoichiometric compounds compared to the stoichiometric compounds [13], possibility (ii) may be more likely than (i).

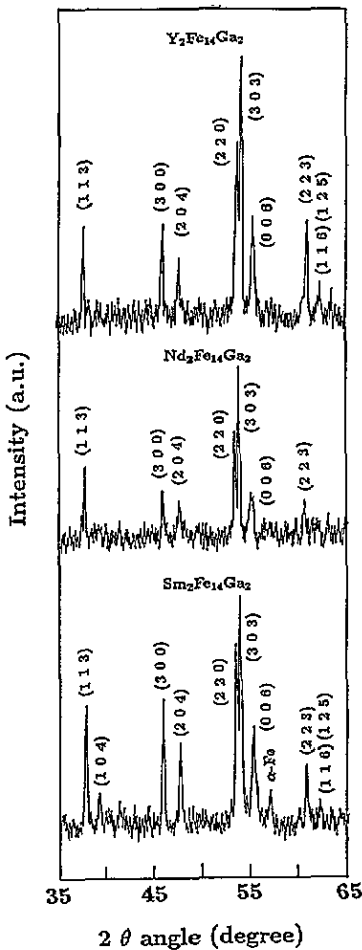


Figure 1. X-ray diffraction patterns of non-aligned $R_2Fe_{14}Ga_2$.

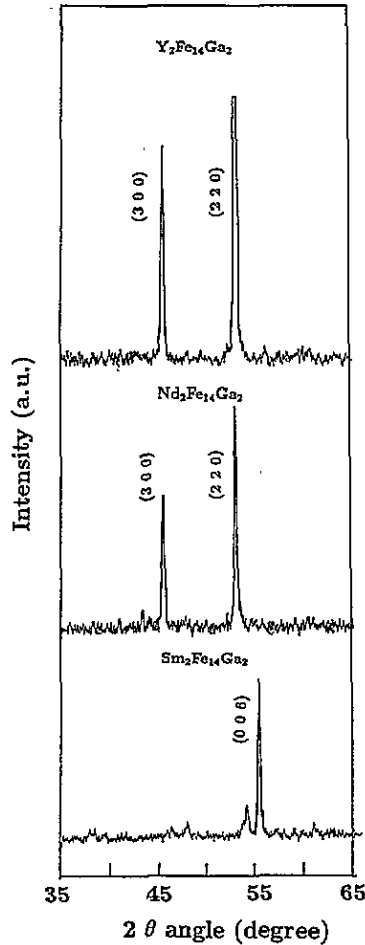


Figure 2. X-ray diffraction patterns of aligned $R_2Fe_{14}Ga_2$.

X-ray diffraction patterns for aligned samples are shown in figure 2. For aligned $Y_2Fe_{14}Ga_2$ and $Nd_2Fe_{14}Ga_2$, the intensities of the (220) and (300) reflections dramatically increase, whereas the intensities of the other reflections almost disappear. This means that the two compounds have an easy c plane anisotropy. By contrast, the greatly increased intensity of the (006) reflection shows that $Sm_2Fe_{14}Ga_2$ has an easy c axis anisotropy. However, because the anisotropy field (see section 3.3) is too small to obtain a fully aligned sample, the intensities of the other reflections do not disappear.

3.2. Mössbauer spectra

Mössbauer spectra at room temperature for $R_2Fe_{14}Ga_2$ together with fitted subspectra are shown in figure 3. The points in the figure are the experimental spectra and the solid lines

represent the fitted curves obtained from computer analysis.

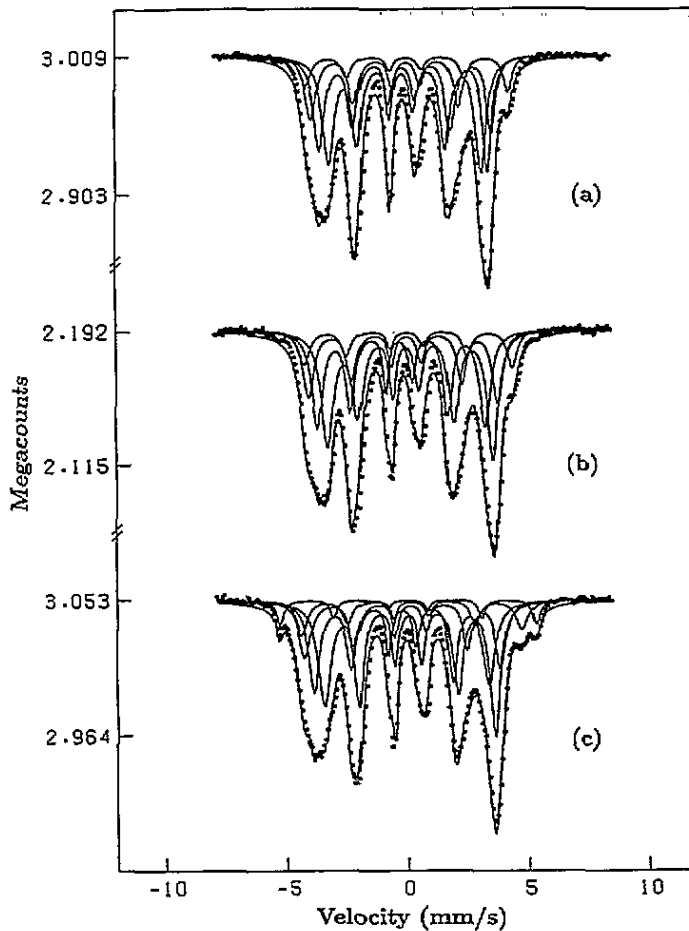


Figure 3. Mössbauer spectra at room temperature for non-aligned $R_2Fe_{14}Ga_2$ together with curves for subspectra, obtained by a computer fit.

Mössbauer spectra for $R_2Fe_{14}Ga_2$ were fitted by four subspectra, which correspond to the four Fe sites. Some constraints were used. The electrical quadrupole interaction was treated as a perturbation on the magnetic dipole interaction. The area ratios of the six absorption lines in each sextet were assumed to be 3:2:1:1:2:3 for non-aligned samples. The corresponding linewidths for the four sextets were constrained to be the same. Each is actually comprised of unresolved overlapping patterns because there may be various numbers of Ga neighbours with different electric quadrupole and magnetic dipole interactions. Consequently, for a given sextet, the six linewidths may be unequal. In addition, a fifth subspectrum, corresponding to α -Fe, had to be added for $Sm_2Fe_{14}Ga_2$. The fitted Mössbauer parameters, isomer shift, δ , quadrupole splitting, ϵ , and hyperfine field, H_{hf} , are listed in table 2.

The relative occupancy numbers on the 6c, 9d, 18f and 18h sites, N_i , are 2:3:6:6. If it is assumed that the recoilless fractions on the four sites are the same, the occupancy fractions

Table 2. Mössbauer parameters at room temperature for $R_2Fe_{14}Ga_2$. Here H_{hf} is the hyperfine field, ϵ is the quadrupole splitting, δ the isomer shift, S is the relative area of each subspectrum associated with each crystallographic site and b is the area ratio of the second plus fifth lines to the third plus fourth lines. b^* and b^+ are for the non-aligned and the aligned samples, respectively.

	Sites	H_{hf} (kOe)	ϵ (mm s^{-1})	δ (mm s^{-1})	S (%)	b^*	b^+
$Y_2Fe_{14}Ga_2$	6c	262	0.04	0.02	10.1	2.0	1.40
	9d	233	-0.20	-0.08	21.1	2.0	1.40
	18f	217	0.06	-0.12	30.9	2.0	1.40
	18h	197	0.15	-0.10	38.0	2.0	1.40
$Nd_2Fe_{14}Ga_2$	6c	269	0.06	0.03	10.6	2.0	1.30
	9d	244	-0.14	-0.09	20.8	2.0	1.30
	18f	216	0.09	-0.28	30.1	2.0	1.30
	18h	213	0.18	0.05	38.6	2.0	1.30
$Sm_2Fe_{14}Ga_2$	6c	284	0.02	0.13	10.4	2.0	0.83
	9d	253	-0.33	-0.07	20.3	2.0	0.83
	18f	226	-0.03	-0.25	29.5	2.0	0.83
	18h	220	0.05	0.05	39.7	2.0	0.83

of the Fe atoms on the i th site, F_i^{Fe} , can be estimated by the formula

$$F_i^{Fe} = \frac{14}{N_i} S_i / \sum_{j=1}^4 S_j \quad (1)$$

where S_i is the area of the i th Mössbauer subspectrum. The results are shown in figure 4. The dotted line in the figure is for random occupancy of the four sites by the Fe atoms. It is obvious that Fe atoms preferentially occupy the 9d and 18h sites and Ga atoms plus vacancies preferentially occupy the 18f and 6c sites. This occupancy trends to elevate the Curie temperature. The details will be discussed in section 3.3.

Quadrupole splittings can give some information on the magnetic anisotropy. It is well known that the quadrupole splitting, ϵ , is related to the angle, θ , between the direction of the hyperfine field and the principal axis of the electric field gradient (EFG) by the equation

$$\epsilon = \frac{1}{4} eq Q (3 \cos^2 \theta - 1) \quad (2)$$

where Q is the nuclear quadrupole moment and q is the component of the EFG along the principal axis. When the magnetic moments are either along the c axis or in the c plane, the quadrupole splitting will be significantly different in sign and/or in magnitude because of the different angles θ . For $Y_2Fe_{14}Ga_2$ and $Nd_2Fe_{14}Ga_2$, the quadrupole splittings are close in magnitude and the same in sign for the corresponding Fe sites. However, as compared to these two compounds, the quadrupole splittings for $Sm_2Fe_{14}Ga_2$ are significantly different in magnitude for the 9d and 18h sites and opposite in sign for the 18f site. Further, the average quadrupole splittings, calculated by weighting their subspectral areas, are 0.04 and 0.07 mm s^{-1} for the Y and Nd compounds, respectively, but -0.05 mm s^{-1} for the Sm compound. Thus, the average quadrupole splittings are opposite in sign. It follows that the magnetic anisotropy for $Y_2Fe_{14}Ga_2$ and $Nd_2Fe_{14}Ga_2$ is different from that for $Sm_2Fe_{14}Ga_2$. This conclusion is also supported by the x-ray diffraction experiments.

To determine the type of anisotropy, we took Mössbauer spectra for the aligned samples. The Mössbauer spectra and their fitted curves are shown in figure 5. In fitting these Mössbauer spectra, all isomer shifts, quadrupole splittings, hyperfine fields, linewidths and

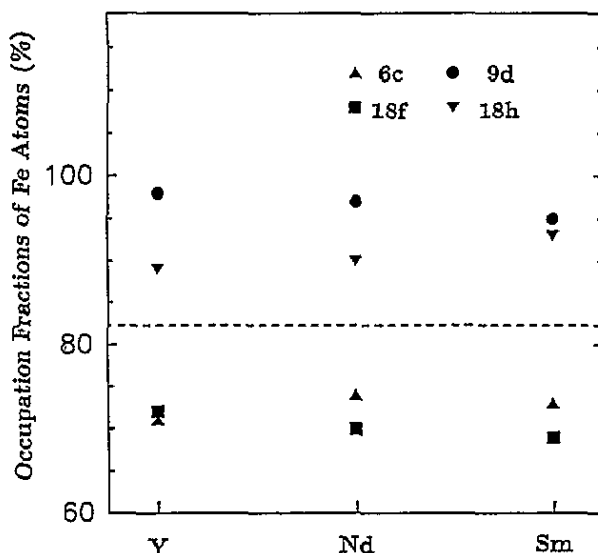


Figure 4. Occupation fractions of Fe atoms on each site for $R_2Fe_{14}Ga_2$. (the dotted line is for random occupancy by the Fe atoms).

the area ratios of the subspectra were constrained to be the same as those for the non-aligned samples. However, the ratio of the six absorption lines in each sextet was assumed to be 3:b:1:1:b:3, where b is a fitted parameter instead of $b = 2$ for the non-aligned samples. The fitted values of b are 1.40, 1.30 and 0.82 for the aligned Y, Nd and Sm compounds, respectively.

The areas of the six absorption lines for a Mössbauer spectrum are related to the direction of the hyperfine field (or magnetic moment) by the relationships

$$\begin{aligned} I_{1,6} &= \frac{3}{4}(1 + \cos^2 \beta) \\ I_{2,5} &= \sin^2 \beta \\ I_{3,4} &= \frac{1}{4}(1 + \cos^2 \beta) \end{aligned} \quad (3)$$

where $I_{i,j}$ represents the relative absorption area of the i and the j lines and β is an angle between the direction of the hyperfine field and the direction of the γ -ray propagation. In our experimental arrangement β represents the angle between the direction of the Fe moments and the normal to the plane of the samples.

For a fully aligned sample, the magnetic moments are along the [001] direction when the sample has an easy c axis anisotropy. The β angle is equal to zero. The area of the second and fifth lines is, therefore, equal to zero by equation (3). When the sample has an easy c plane anisotropy, the moments can lie on the [100], [110] and [010] directions; the angles, β , are thus 0° , 60° and 120° for these three directions, respectively. Thus, the value of b is given by

$$b = \frac{\sum_i^3 4 \sin^2 \beta}{\sum_i^3 (1 + \cos^2 \beta)} = 1.33. \quad (4)$$

The fitted values of $b = 1.40$ and 1.30 for $Y_2Fe_{14}Ga_2$ and $Nd_2Fe_{14}Ga_2$ are indeed very close to 1.33. This shows that the two compounds have an easy c plane anisotropy, which is consistent with results obtained from x-ray diffraction. In addition, the value of b for $Sm_2Fe_{14}Ga_2$ should be zero. However, because the anisotropy field is too small to obtain a

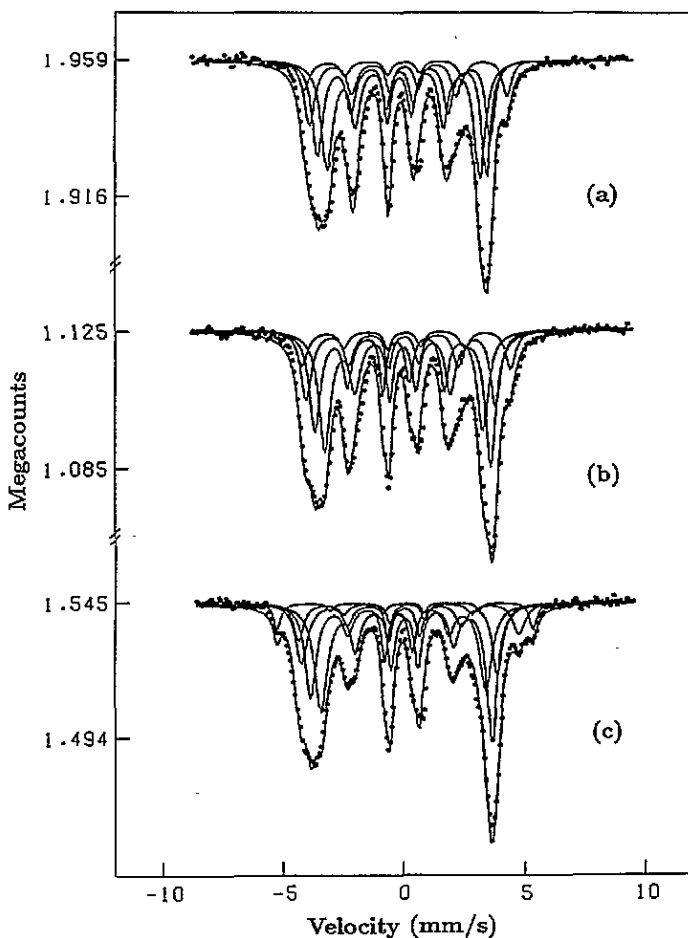


Figure 5. Mössbauer spectra at room temperature for aligned $R_2Fe_{14}Ga_2$ together with curves for subspectra, obtained by a computer fit.

fully aligned sample, the experimental value of b deviates substantially from the theoretical value of zero.

3.3. Magnetic properties

3.3.1. Curie temperature and saturation magnetization. Thermomagnetic scans for $R_2Fe_{14}Ga_2$ are shown in figure 6. The Curie temperatures and the saturation magnetizations for $R_2Fe_{14}Ga_2$ are listed in table 3. In addition, the data for R_2Fe_{17} [18] are listed in the table for comparison.

The saturation magnetization of $Y_2Fe_{14}Ga_2$ at room temperature is 116 emu g^{-1} , which corresponds to $22.8 \mu_B$ per chemical formula. The Fe moment is calculated to be $1.65 \mu_B$, which is smaller than the $2.2 \mu_B$ for α -Fe metal.

However, when non-magnetic atoms Ga replace Fe in R_2Fe_{17} , the Curie temperatures are elevated. The Curie temperatures are 478, 526 and 541 K for $Y_2Fe_{14}Ga_2$, $Nd_2Fe_{14}Ga_2$ and $Sm_2Fe_{14}Ga_2$, respectively, which are 154, 199 and 173 K higher than those for the

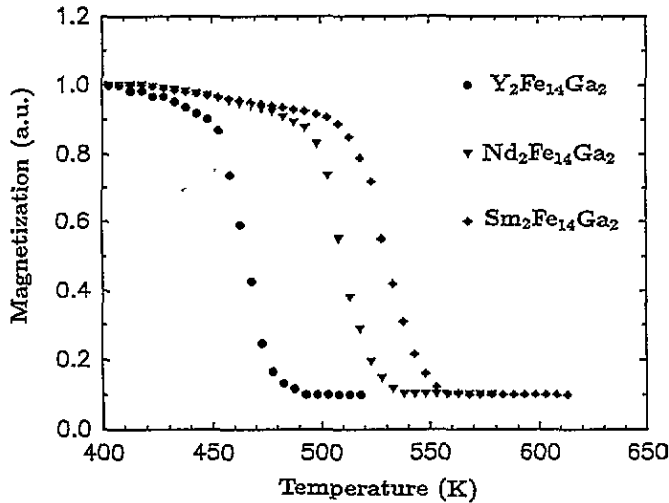


Figure 6. Thermomagnetic scans for $R_2Fe_{14}Ga_2$.

Table 3. Magnetic properties of $R_2Fe_{14}Ga_2$. Here T_f is the Curie temperature, σ is the specific saturation magnetization, μ/FU is the moment per chemical formula unit, μ_{Fe} is the Fe moment, μ_R is the R moment and H_a is the anisotropy field.

	T_f (K)	σ (emu g ⁻¹)	μ/FU (μ_B)	μ_{Fe} (μ_B)	μ_R (μ_B)	H_a (kOe)	Type of anisotropy
$Y_2Fe_{14}Ga_2$	478	116	22.8	1.63	0	28	plane
Y_2Fe_{17} [18]	324						plane
$Nd_2Fe_{14}Ga_2$	526	116	25.1	1.63	1.14	48	plane
Nd_2Fe_{17} [18]	327						plane
$Sm_2Fe_{14}Ga_2$	541	119	26.0	1.63	1.60	10	axis
Sm_2Fe_{17} [18]	368						plane

corresponding R_2Fe_{17} .

Based on the theory of the competition between the positive and negative interactions [19, 20], the Curie temperature, T_f , can be expressed as

$$T_f = T_+ - T_- + T_{R-Fe}. \quad (5)$$

The first term in equation (5) is the contribution of the positive exchange interactions to the Curie temperature. For Fe-based alloys with a low solvent concentration, the Curie temperatures on the solvent concentrations can be considered to be linear to a good approximation. Therefore, the Curie temperatures can be written as

$$T_+ = T_0(1 - \alpha x) \quad (6)$$

where T_0 is assumed to be the Curie temperature (1043 K) for α -Fe, x is the Ga concentration and α is a coefficient. Based on the literature for Fe-Ga alloys with low Ga concentration [21], α is taken as 0.032.

The second term is the contribution of the negative exchange interactions. For R_2Fe_{17} , there exists a critical interatomic distance, 2.45 Å, for the exchange interaction [22]. When the distance of the Fe-Fe pairs is larger than 2.45 Å, the interactions are positive; at smaller

Fe-Fe distances, the interactions are negative. According to [20], the negative exchange interactions can be expressed as

$$T_- = \beta J_- n_- \quad (7)$$

where $\beta = \frac{2}{3}S(S+1)/k$ is a constant, J_- is the negative exchange integral and n_- is the average number of Fe-Fe pairs with a negative interaction for a given Fe atom, viz.

$$n_- = \frac{1}{17} \sum_{i=1}^4 N_i F_i^{Fe} \sum_{j=1}^4 F_j^{Fe} Z_{j2} \quad (8)$$

where Z_{j2} is the number of Fe-Fe pairs with a negative interaction for a given j site. The values of n_- as well as T_- are related to the occupancies by Fe (or Ga) atoms on certain sites. First, F_i^{Fe} , the occupancy fractions of Fe atoms on the i th site, can be obtained from equation (1). Second, for the 2:17-type compounds, the exchange interactions on the 6c-6c and 18f-9d atomic pairs are negative because their interatomic distances are 2.389 and 2.436 Å. Thus, the values of n_- are calculated to be 1.084, 1.047 and 1.006 for the Y, Nd and Sm compounds, respectively.

The third term is the contribution of the R-Fe interaction. Because the Curie temperatures are 324, 327 and 369 K for Y_2Fe_{17} , Nd_2Fe_{17} and Sm_2Fe_{17} , respectively [18], the terms T_{R-Fe} are taken as 3 and 45 K for $Nd_2Fe_{14}Ga_2$ and $Sm_2Fe_{14}Ga_2$, respectively.

Table 4. The Curie temperature calculated by (5), (6) and (7). ($T_0 = 1043$ K and $\beta J_- = 425$ K are used. α is 0.032 and zero for $R_2Fe_{14}Ga_2$ and R_2Fe_{17} , respectively.)

	n_-	T_+ (K)	T_- (K)	T_{R-Fe} (K)	T^{cal} (K)	T^{exp} (K)
$Y_2Fe_{14}Ga_2$	1.084	942	461	0	481	478
$Nd_2Fe_{14}Ga_2$	1.047	942	445	3	500	526
$Sm_2Fe_{14}Ga_2$	1.006	942	428	44	558	541
Y_2Fe_{17}	1.530	1043	650	0	393	324
Nd_2Fe_{17}	1.530	1043	650	3	396	327
Sm_2Fe_{17}	1.530	1043	650	44	437	369

The results calculated from equation (5) are listed in table 4. The predicted Curie temperatures are close to the experimental values. In addition, the Curie temperatures for R_2Fe_{17} are also calculated based on this model and the results are listed in table 4. For R_2Fe_{17} , the average number of Fe-Fe pairs for a given Fe atom is calculated to be 10; among these the average number with negative exchange interaction is 1.53. Consequently, the Curie temperatures for R_2Fe_{17} compounds are rather low. For $R_2Fe_{14}Ga_2$, Ga atoms preferentially occupy the 18f and 6c sites, which reduce the magnitude of the negative exchange interactions for the 6c-6c and 18f-9d atomic pairs. As a consequence, their Curie temperatures are elevated.

3.3.2. Magnetic anisotropy. In order to determine the anisotropy field, magnetization curves with the fields applied parallel and perpendicular to the alignment direction were obtained; the data are shown in figure 7. The anisotropy fields, H_a , for $Nd_2Fe_{14}Ga_2$ and $Y_2Fe_{14}Ga_2$ were estimated by extrapolating the linear part of the magnetization curves for $H_{||}$ and H_{\perp} from the maximum applied field (18 kOe) to their point of intersection. The results are listed in table 3. Although $Nd_2Fe_{14}Ga_2$ possesses a large anisotropy field of 48 kOe, the easy magnetization direction is in the c plane according to the x-ray diffraction

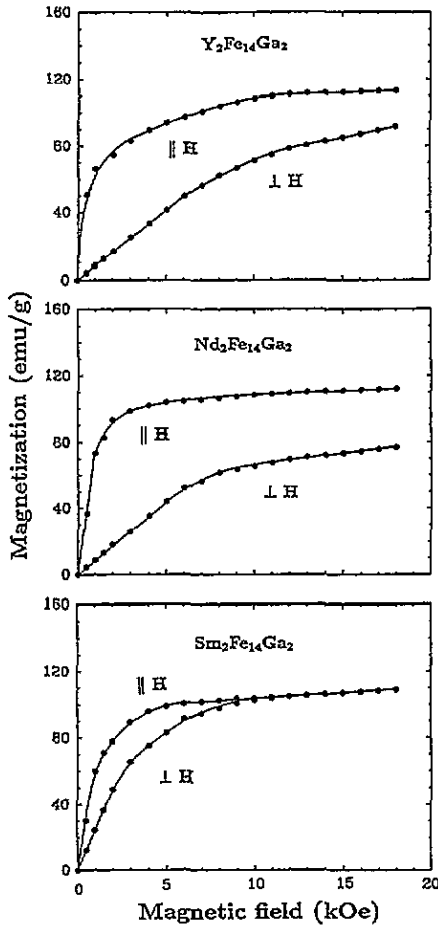


Figure 7. Magnetization curves of aligned $R_2Fe_{14}Ga_2$ parallel and perpendicular to the aligned direction. For Y and Nd compounds, the easy magnetization direction (parallel to the aligned direction) is in the c plane and the hard magnetization direction (perpendicular to the aligned direction) is along the c axis; for the Sm compound, the easy magnetization direction is along the c axis and the hard magnetization direction is in the c plane.

and Mössbauer spectra (see sections 3.1 and 3.2). On the other hand, x-ray and Mössbauer spectra imply that the $Sm_2Fe_{14}Ga_2$ compound has an easy c axis anisotropy. However, the anisotropy field is rather small, only about 10 kOe, as calculated from the magnetization curves. Hence, the magnetic anisotropy for the off-stoichiometric $R_2Fe_{14}Ga_2$ differs greatly from that for the off-stoichiometric $R_2Fe_{14}Si_2$, but is similar to that for stoichiometric $Sm_2Fe_{15}Ga_2$. $R_2Fe_{14}Si_2$ compounds have an easy c axis anisotropy for the Y and Nd compounds and an easy c plane anisotropy for the Sm compound [14, 15]; the stoichiometric $Sm_2Fe_{17-x}Ga_x$ compounds have an easy c axis anisotropy when $x \geq 2$ [13].

For all the R_2Fe_{17} compounds the Fe sublattice has an easy c plane anisotropy that is larger than the anisotropy of the R sublattice at room temperature. As a result, all R_2Fe_{17} compounds have an easy c plane anisotropy, even though the R sublattice has an easy c axis anisotropy for the Sm, Er and Tm compounds. Inomata [23] has performed point charge calculations at the Co sites for the Y_2Co_{17} compound; he found that the 18f sites have an

easy c axis anisotropy whereas the other three sites have an easy c plane anisotropy. On the other hand, the Stevens factor, α_J , has a different sign for Co ($3d^8$) from that for Fe ($3d^6$ or $3d^7$) [24]. Hence, the contributions of Fe and Co to the magnetic anisotropy have opposite signs for each site in the isostructural compounds. It follows that, for the R_2Fe_{17} compounds, the 18f sites will give an easy c plane anisotropy. When the Ga replaces Fe in $R_2Fe_{14}Ga_2$ and preferentially occupies the 18f sites, the easy c plane anisotropy of the Fe sublattice becomes weaker and is surpassed by the easy c axis anisotropy of the Sm sublattice. Thus, the easy magnetization direction changes to the c axis for $Sm_2Fe_{14}Ga_2$ as compared to the c plane for Sm_2Fe_{17} . However, the easy magnetization direction still remains in the c plane for $Nd_2Fe_{14}Ga_2$ because the Nd sublattice also has an easy c plane anisotropy.

4. Conclusions

All off-stoichiometric compounds $R_2Fe_{14}Ga_2$ ($R = Y, Nd$ and Sm) have the Th_2Zn_{17} structure. The lattice parameters, a and c , increase as compared to those for the corresponding R_2Fe_{17} compounds.

The Curie temperatures are 478, 526 and 541 K for Y, Nd and Sm compounds, respectively, which are 154, 199 and 173 K higher than those for the corresponding R_2Fe_{17} . Mössbauer spectra show that the Fe atoms preferentially occupy the 9d and 18h sites whereas the Ga atoms prefer the 18f and 6c sites. These occupancies lead to a decrease in magnitude of the negative exchange interaction between the 18f–9d and 6c–6c atom pairs. The total interaction then becomes stronger; hence the Curie temperature is elevated. A model that considers the competition between positive and negative interactions was used to predict the Curie temperatures of $R_2Fe_{14}Ga_2$; the values obtained are consistent with the experimental results.

Both x-ray diffraction and Mössbauer spectra of aligned samples show that $Nd_2Fe_{14}Ga_2$ and $Y_2Fe_{14}Ga_2$ have an easy c plane anisotropy; however, $Sm_2Fe_{14}Ga_2$ has an easy c axis anisotropy with an anisotropy field of 10 kOe. The two different types of anisotropy have their origin in the occupancy of the Ga atoms on the 18f sites and in the single-ion model.

Acknowledgments

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